Vegetation: aerial canopy survey

Version 1.0

This specification was prepared by Alan Rose in 2012.

Contents

Department of Conservation
Te Papa Atawhai

Synopsis

Many factors can contribute to canopy dieback (mortality and defoliation) in native forests, including drought, natural stand dynamics, pathogens, and browsing by possums and insects. The role of possums and other factors in dieback can be effectively explained using the concepts of predisposing and trigger factors (Stewart & Rose 1988; see also Reif & Allen 1988). Predisposing factors are underlying long-term stresses that make forests vulnerable to dieback, such as genetic composition or tree ageing. In contrast, trigger factors are short-term stresses that are the immediate cause of dieback, such as heavy browsing or severe drought.

For conifer-broadleaved forests dominated by possum-preferred species like southern rātā, northern rātā, Hall’s tōtara, and kāmahi, possums can severely defoliate individual trees (e.g. Meads 1976, Payton 1988, Leutert 1988, Smale et al. 1995) and there is little doubt that browsing has been a predominant trigger of the extensive and synchronous dieback recorded over the last c. 40–50 years. However, natural stand and landscape dynamics are important predisposing factors (Stewart & Rose 1988; Reif & Allen 1988). Hence broad dieback patterns have been shown to correspond with patterns of liberation, colonisation and length of occupation by possums, for both conifer-broadleaved forest (Pekelharing & Reynolds 1983; Rose et al. 1992, 1993) and mixed beech-broadleaved hardwood forest (Rose et al. 1993). However, within such patterns some communities are more predisposed to possum-triggered dieback than others. For example, (a) forests on unstable schist are more highly predisposed than on stable granite, because they contain abundant, highly-preferred, small understorey and seral trees such as fuchsia, wineberry and patē in canopy gaps or on landslide debris, and (b) as even-aged rātā stands on landslide scars age, the old trees become less able to withstand ongoing defoliation by possums, canopy gaps increase, and palatable understorey and seral species become more abundant, providing additional food for possums (Payton 1988; Reif & Allen 1988; Stewart & Rose 1988).

In the 1980s it was recognised that the lack of a good overview of canopy condition meant that past possum control had often been ad hoc, too infrequent, and ultimately ineffective in protecting forest canopies (Batcheler & Cowan 1988). Consequently, the aerial canopy survey (ACS) method was developed to provide a comprehensive assessment of canopy condition through mapping broad patterns in canopy condition and composition over large areas, typically comprising tens to hundreds of thousands of hectares. The primary purpose of ACS is to inform decisions about priority areas for possum control and undertake monitoring of possum impacts. ACS alone will not provide sufficient information to assess historical, current, or potential future possum impacts. Prioritisation is achieved through integrating canopy survey results with the history of possum liberation and spread (e.g. from residual trap catch monitoring of possum populations), geographic and environmental gradients in forest composition and susceptibility to browsing, past dieback patterns, the distribution of threatened flora and fauna, and any other relevant information available (Rose 1994; Rose, Pekelharing et al. 1995; Rose, Platt et al. 1995).

ACS is more rapid, practical, and cost-effective than ground surveys over large areas. For example, canopy composition and dieback in South Westland were assessed from a helicopter at the rate of approximately 15 000 ha per hour. Thus, three skilled observers fully assessed 265 000 ha within a week—an area that would have taken months to sample using ground survey teams. The method was developed from earlier canopy and ground surveys in parts of Westland (Pekelharing & Reynolds 1983; Rose et al. 1988; see also Leutert 1988 and Smale et al. 1995) and later refined in the 1980s to survey 83 000 ha of rātā-kāmahi forest that was highly susceptible to possum browsing along the eastern side of the Alpine Fault (Rose et al. 1992). Although conspicuous dieback had been a feature of these forests for at least 40 years, at that stage there was still no comprehensive picture of the magnitude and pattern of damage to help assess overall priorities for possum control (Chavasse 1955; Batcheler & Cowan 1988). The method was further refined and adapted in the mid-1990s to survey the impact of invading possum populations on the mixed beech-broadleaved forests of South Westland (156 000 ha; Rose et al. 1993; Rose & Pekelharing 1995) and to help prioritise areas for possum control in similar forests of Nelson/Marlborough (265 000 ha; Rose, Platt et al. 1995). Other surveys included beech and beech-broadleaved forest in Otago (e.g. Burrows et al. 1997; Smale et al. 1996), broadleaved-conifer and beech forests in the Ruahine Range (33 500 ha; Rogers & Leathwick 1997), and coastal pōhutukawa forest in the Bay of Plenty (Kate McNutt, pers. comm.). Parts of South Westland were re-surveyed in 1992 (Rose & Pekelharing 1995) and parts of Central Westland in 2006 (Phil Knightbridge, pers. comm). The method is still undergoing refinements and has not yet been tested in all types of forest, such as (a) lowland North Island forest in finely dissected low hill country, (b) forest with a long history of possum occupation, (c) forest with highly mixed canopies, and (d) little highly palatable seral forest.

Examples of questions that ACS can help to address include:

- What proportion of the canopy shows conspicuous dieback?
- What are the main species showing dieback?
- Does the severity of dieback vary within the survey area?
- Where is dieback most pronounced?
- Where are the forests least modified by possums?
- What areas are most susceptible to possum browsing?
- Do dieback patterns reflect the history of possum liberation and spread?

ACS requires skilled ecologists to map and interpret dieback patterns. Dieback is defined as including all conspicuous defoliation and mortality because defoliation and mortality cannot be distinguished consistently at the broad and variable scales of investigation used in ACS. This definition may be broader than for other more intensive methods that examine individual trees, such as foliar browse index (FBI) (Payton et al. 1997) or aerial FBI. Although the data represents a subjective assessment of defoliation, dieback scores assessed from recent aerial photographs have been shown to correlate well with those made on newly established 20 × 20 m plots by ground crews (Rose et al. 1988). The exact approach used for ACS depends on three main factors: (1) the availability of recent aerial photographs, (2) whether the canopy is dominated by possum-preferred species or by less palatable species (generally beech), and (3) the amount of highly palatable seral forest.

Generally there are four stages of assessment that take place in the office and then subsequently in the field. For more information about these stages refer to 'Full details of technique and best practice'.

Office based:

1. Delineating the map units (also called polygons) to be assessed on 1:50 000 maps. Map units are generally forest tracts of about 1–2 km^2 that have readily identified boundaries such as creeks, ridges, and bluff systems. Unit boundaries may be revised during the survey (Fig. 1). So far, most ACS studies have been in mountainous terrain, where map units are commonly 1–2 km long and extend from treeline to valley floor. Other approaches could be used in gentler terrain or areas with less well-defined drainage systems, e.g. by gridding the survey area into contiguous, more-or-less even sized units.
2. Analysing the amount of conspicuous canopy dieback (defoliation and mortality) on recent aerial photographs, if available.

Field work:

3. Helicopter-based surveys of conspicuous canopy dieback (defoliation and mortality) and canopy composition in all or some selected map units.
4. Rapid helicopter and ground-based inspections of selected dieback areas to assess possum impacts in more detail.

It is important to note that ACS is a snapshot of the canopy at a point in time. Observers can only score dieback that is currently visible and old dieback events may not show up because dead trees have decayed and collapsed. Thus, areas currently exhibiting nil, light, or moderate dieback may have undergone more severe dieback in the past. Interpretation of dieback patterns and their causes involves integration of the survey results with all other available information.

Assumptions

- For possum-preferred species, the observed dieback has been triggered primarily by possum browsing unless there is current or historical evidence to the contrary. This assumption needs to be tested as far as practicable by the field work and by reviewing and integrating all available information.
- Mapping methods are standardised and fixed for the duration of the study and in all re-surveys of the area. This includes using the same definitions of dieback, scoring the same dieback and canopy cover classes, and re-scoring the same map units.
- Observer effort and skills, including the ability to correctly detect and score dieback and canopy cover are similar for all map units and surveys.
- The total canopy, or a sufficiently representative proportion of the canopy, is assessed for all map units/polygons and surveys.
- Subjective estimates of dieback and canopy cover are reasonably accurate and consistent between observers.
- For helicopter-based surveys, there is good a priori knowledge of which possum-preferred canopy species need to be assessed.
- Areas chosen for rapid helicopter or ground-based inspections are representative of others with similar levels of observed dieback and are sufficient to elucidate the role of possums in observed dieback.

Advantages

- A practical, flexible, repeatable and cost-effective method for rapidly surveying large areas.
- Faster and less expensive than ground surveys (such as foliar browse index).
- Capable of providing more detail than remote sensing alone.
- The surveys of dieback and canopy cover are cost-effective if using skilled observers. Note, however, that reviewing all relevant information, analysing survey results, and adequately integrating and interpreting the study will add significantly to the cost.
- Provides an overview of the broad patterns in canopy cover and dieback over the entire study area.
- Results are readily communicated using maps.
- Aerial photographs can be archived and future reference should allow some calibration of scoring between surveys even with different observers.
- Capable of detecting moderate to large differences in canopy condition between areas or over time if assumptions about observer effort and equal rates of detecting dieback and possum-preferred species are met.
- Specifically targeted at providing information to help identify priority areas for possum control or more detailed monitoring.
- Applicable over a wide range of forest types containing possum-preferred canopy trees and/or seral forest.

Disadvantages

- Specifically requires two or three highly skilled and trained observers.
- Becomes more difficult to interpret dieback patterns when (a) mature forests contain very low proportions of possum palatable species, (b) there is little palatable seral forest, and/or (c) the area has a long history of heavy modification by possums which has resulted in canopy collapse and replacement by unpalatable species.
- Subjective estimates need to be interpreted cautiously when comparing different observers or surveys.
- Unlikely that the ability of different observers to detect dieback can be compared between re-surveys of the same study area.
- May underestimate past dieback because of tree decay.
- May underestimate understorey depletion by possums unless ground surveys are comprehensive.
- Not designed for detailed assessment of forest dynamics or understorey composition and condition.
- Less suitable for uncommon and inconspicuous canopy species.
- The method has not yet been tested in all types of forest, such as (a) lowland North Island forest in finely dissected low hill country, (b) forest with a long history of possum occupation, (c) forest with highly mixed canopies, and (d) little highly palatable seral forest.

Suitability for inventory

- Specifically developed for rapid inventory of large areas to determine priority areas for possum control and/or to stratify to establish more intensive possum-impact monitoring.
- Not designed for comprehensive surveys of the forest understorey.
- For maximum interpretation, results need to be integrated with other relevant information, which may greatly increase costs (see ‘Minimum attributes’).

Suitability for monitoring

- Capable of detecting moderate to large temporal changes if methods and survey design have been standardised and well documented. However, subjective estimates of dieback need to be interpreted cautiously to assess whether a true change has occurred.
- For maximum interpretation, results need to be integrated with other relevant information, which may greatly increase costs.

Skills

- A high level of skill in interpretation of aerial photographs and assessing canopy dieback and species composition from a helicopter.
- A high level of skill in interpreting the results in relation to other information, including possum population history, past dieback patterns, and gradients in forest composition and susceptibility to browsing.
- Observers need to be able to stomach substantial periods of time observing and recording while in a helicopter.
- Training in ground-inspection methods.
- Training in the safe use of helicopters.

Resources

- Recent high-quality aerial photographs of the entire survey area, preferably GIS registered.
- Appropriate GIS computing facilities (hardware and software), if required by objectives.
- The helicopter-based canopy survey requires at least two and preferably three trained observers. An experienced team can expect to fly for 2–6 hours per day, depending on survey complexity and flying conditions. The canopy survey is mentally and physically demanding. To ensure high quality results, flying should be terminated if observers can no longer concentrate effectively or become impaired because of nausea.
- Requires one or more teams of two people for ground inspections. Except in remote areas, an experienced ground team can generally assess one or two areas per day (> 50 trees per area).
- Standard field equipment: maps, pens, clipboard, datasheet, compass, GPS unit, binoculars.
- The cost of data analysis, and interpreting and reporting the results should not be underestimated as they generally need to include a review of all other relevant habitat and animal pest information.

Minimum attributes

These attributes are critical for the implementation of the method. Other attributes may be optional depending on your objective. For complex and extensive surveys, it is useful to display all data spatially using GIS software. However, this may not be required by the objectives and is not critical if resources are limited. For more information refer to 'Full details of technique and best practice'.

DOC staff must complete a 'Standard inventory and monitoring project plan' (docdm-146272).

Aerial photograph analysis:

- Survey name and date
- Observers' names
- Date of assessment
- Map unit or polygon number
- Catchment name/geographic location
- Aerial photograph number and date
- NZMS 260 map number
- Proportion of mature forest canopy showing dieback
- Proportion of seral forest
- Proportion of seral forest dieback
- Categories used for scoring (refer to 'Full details of technique and best practice' for these)

Helicopter-based survey:

- Survey name and date
- Observers' names
- Date of assessment
- Map unit/polygon number
- Catchment name/geographic location
- NZMS 260 map number
- Proportions of the main possum-preferred species in the mature forest canopy
- Proportion of the mature forest canopy showing conspicuous dieback of possum-preferred species and the main species involved
- Presence/absence of localised heavier dieback of possum-preferred species in map units with < 10% overall mature-forest dieback
- Proportion of the mature forest canopy showing conspicuous dieback of beech (or other dominant unpalatable species)
- Proportion of seral forest dominated by possum-preferred species
- Proportion of seral forest dieback and the main species involved
- Categories used for scoring (refer to 'Full details of technique and best practice' for these)

Rapid aerial inspections:

- Map unit/polygon number

- Observers, date, etc. (as above)
- GPS location
- Severity of possum browsing damage
- Severity of other damage (snowfall, salt spray, etc.)

Rapid ground inspections:

- Map unit/polygon number
- Transect number
- Observers, date, etc. (as above)
- Severity of possum browsing damage and dieback for each tree
- Number of dead standing trees

Interpretation will be greatly enhanced, particularly for evaluating possum control priorities, if at least some of the following optional attributes and information are assessed and reviewed:

- History of possum liberation and spread, including past and current density and distribution estimates, e.g. residual trap catch indices.
- Geographic and environmental gradients in forest composition. These are most useful when obtained from actual forest plot data, e.g. from the National Vegetation Survey database. Broader forest types can be obtained from LCDB II and Eco Sat maps, New Zealand Forest Service forest type maps (e.g. Newsome 1987), or other sources.
- Geographic and environmental gradients in forest susceptibility to browsing by possums and other animal herbivores. This will largely reflect patterns in the abundance of key palatable indicator species and is determined from more detailed analysis of forest composition data, where available.
- Past canopy dieback patterns.
- Distribution and abundance of threatened flora and fauna.
- History of other animal herbivore populations, including current pest abundance indices such as deer pellet counts or residual trap catch for possums.
- Historical climate data, such as severe droughts.
- Parent material, as an index of site stability, drainage and fertility. For example, Westland rātā-kāmahi forests on stable granite are less predisposed to extensive possum-triggered dieback than those on unstable schist (Reif & Allen 1988).

Data storage

Forward copies of completed survey sheets to the survey administrator, or enter data into an appropriate spreadsheet as soon as possible. Collate, consolidate and store survey information securely, also as soon as possible, and preferably immediately on return from the field. The key steps here are data entry, storage and maintenance for later analysis, followed by copying and data backup for security.

Summarise the results in a spreadsheet or equivalent. Arrange data as ‘column variables’—i.e. arrange data from each field on the data sheet (date, time, location, plot designation, number seen, identity, etc.) in columns, with each row representing the occasion on which a given survey plot was sampled.

If data storage is designed well at the outset, it will make the job of analysis and interpretation much easier. Before storing data, check for missing information and errors, and ensure metadata are recorded.

Storage tools can be either manual or electronic systems (or both, preferably). They will usually be summary sheets, other physical filing systems, or electronic spreadsheets and databases. Use appropriate file formats such as .xls, .txt, .dbf or specific analysis software formats. Copy and/or backup all data, whether electronic, data sheets, metadata or site access descriptions, preferably offline if the primary storage location is part of a networked system. Store the copy at a separate location for security purposes.

Analysis, interpretation and reporting

Standardised analysis and interpretation allows comparisons to be made at different sites and at different times. Follow these instructions when analysing and interpreting data from ACS.

Seek statistical advice from a biometrician or suitably experienced person prior to undertaking any analysis.

Maps illustrating spatial patterns in the variables assessed, such as canopy dieback, canopy cover, and proportion of seral forest can be drawn manually, or if resources and objectives permit they are best generated by digitising the field maps, using GIS software such as ARCINFO or TERRASOFT. Each map unit/polygon is colour-coded according to the value of the dieback or cover class or any other parameter assessed (e.g. length of occupation by possums, presence of a rare plant or animal species). The area of each map unit/polygon is calculated by the GIS program, and can be used to analyse the proportions of the survey area occupied by each dieback class, cover class, or any other parameter assessed using the GIS program or spreadsheets. The results from ground inspections can be summarised for each species and overall using spreadsheets. Rose, Platt et al. (1995) calculated four statistics from the data, using similar techniques as the now recommended foliar browse index method (Payton et al. 1999):

- Mortality: the proportion of dead standing trees.
- Browsing frequency: the proportion of live trees with browsing damage.
- Browsing intensity: the proportion of trees showing moderate to severe browsing (> 25% of the crown browsed).
- Severity of crown death: the proportion of trees showing moderate to severe crown death (> 25% of the crown affected).

Simple tables, graphs, and statistics can be used to compare different parts of a survey area. For example, Rose et al. (1992) showed that the amount of dieback in three areas of Westland increased with increasing duration and intensity of possum browsing assessed from possum liberation records. Formal statistical analyses may not be necessary, but can be conducted if required. These are again fairly simple, e.g. using non-parametric statistics such as χ^2.

Interpretation is greatly enhanced by assessing covariates such as the history of possum liberation and spread, geographic and environmental gradients in forest composition, geographic and environmental gradients in forest susceptibility to browsing by possums and other animal pests, past canopy dieback patterns, the distribution and abundance of threatened flora and fauna, and the history of other feral herbivore populations.

Case study A

Case study A: priority areas for possum control in Nelson/Marlborough Conservancy

Synopsis

In 1993, Nelson/Marlborough Conservancy contracted Landcare Research to assist in assessing possum control priorities throughout the Conservancy. The first stage in this assessment was to review available information on possums and possum-vulnerable species (Rose 1994). The second stage was to survey and map the distribution and abundance of possum-preferred canopy species and the present distribution and magnitude of forest dieback attributable to possums (Rose, Platt et al. 1995). The third stage was to integrate all available information to recommend priority areas for possum control or further assessment (Rose, Pekelharing et al. 1995). The approach was more ecosystem-based than earlier surveys by recognising that threatened species depend on ecosystems and common forest types contain a high proportion of a conservancy's biodiversity (Ogden 1991; Rose 1993). This meant integrating the need, as far as possible, to protect (a) a representative range of possum-vulnerable forest types, and (b) the many individual species of threatened plants and animals found in the conservancy, e.g. mistletoes, *Raukaua edgerleyi*, kākā, and Powelliphanta land snails. Some of these special species do not necessarily favour forest types dominated by highly-vulnerable canopy species. These sometimes conflicting goals were reconciled by selecting priority areas within a framework that encompassed the major geographic and environmental gradients in forest composition. Clear knowledge of the conservation values at stake, as reflected in forest composition and the location of threatened species, helped determine the recommended location and size of each priority area, appropriate control methods, and the desired outcomes of control—whether protection of threatened species, vulnerable forest types, or both (Rose, Pekelharing et al. 1995).

Objectives

Stage 1: Information review

- Summarise and map the susceptibility of different forest types to possum damage and the distribution of 'special' flora and fauna that are highly susceptible to possums (including kākā, kiwi, and land snails).

- Summarise and map the history of liberation and spread of possum populations, present densities, geographic barriers to spread, and the extent of possum-induced forest modification.
- Summarise and map the distribution of feral ungulates.
- Identify information gaps and establish a basis for aerial and ground-based surveys of selected areas.

Stage 2: ACS

- Survey and map the distribution and abundance of possum-vulnerable canopy species.
- Survey and map the distribution and magnitude of canopy dieback.
- Assess the role of possums in observed dieback.

Stage 3: Identify priority areas for possum control

- Develop a framework for protecting a representative range of possum-vulnerable ecosystems and species.
- Recommend priority areas for possum control.
- Identify requirements for further assessments of possum impacts.

Sampling design and methods

Stage 1: Information review

- The Conservancy was divided into 14 management areas that formed the basic units for investigation. These were delineated by a combination of DOC operational criteria, availability of information, and broad homogeneity of environment and ecosystems.
- Forest susceptibility was assessed using compositional information, particularly the occurrence of 39 key possum-preferred and non-preferred species identified in earlier reports and papers (e.g. Rose et al. 1992). Three complementary sources of information of varying detail were used in the assessment:
    - — A multivariate classification of all-species RECCE data from 4200 forest plots held in the National Vegetation Survey (NVS) database
    - — Forest Class Maps (canopy composition only)
    - — Published and unpublished reports
- The number of possum-vulnerable plant taxa in the ‘Threatened’ and ‘Local’ categories (‘Special Vulnerable species’) was assessed from published and unpublished records.
- The distribution of kiwi, kākā, and 35 land snail taxa was assessed and mapped from published and unpublished reports and databases.
- The establishment, distribution, and impacts of possums, red deer, goats and pigs were reviewed and mapped from available literature and information.
- A total of 14 maps were produced using TERRASOFT software.
- All information was integrated to identify the most susceptible management areas.

Stage 2: ACS

- Of the approximately 1 million hectares of DOC administered land in Nelson/Marlborough, 16 areas totalling 265 140 ha were selected for surveys of canopy composition and dieback. The survey sampled forests throughout the Conservancy, from sea-level to treeline, but primarily focused on forests identified from the review as highly and moderately susceptible to possums. It also sampled near-pure beech forest containing threatened flora and fauna and/or highly vulnerable seral communities.
- As there was little obvious dieback on aerial photographs, the 16 survey areas were divided into 130 map units which were assessed individually by two or three observers operating from a helicopter (Fig. 1). Units were delineated by prominent topographic features such as ridges and rivers and marked on 1:50 000 maps (2–17 map units per area).

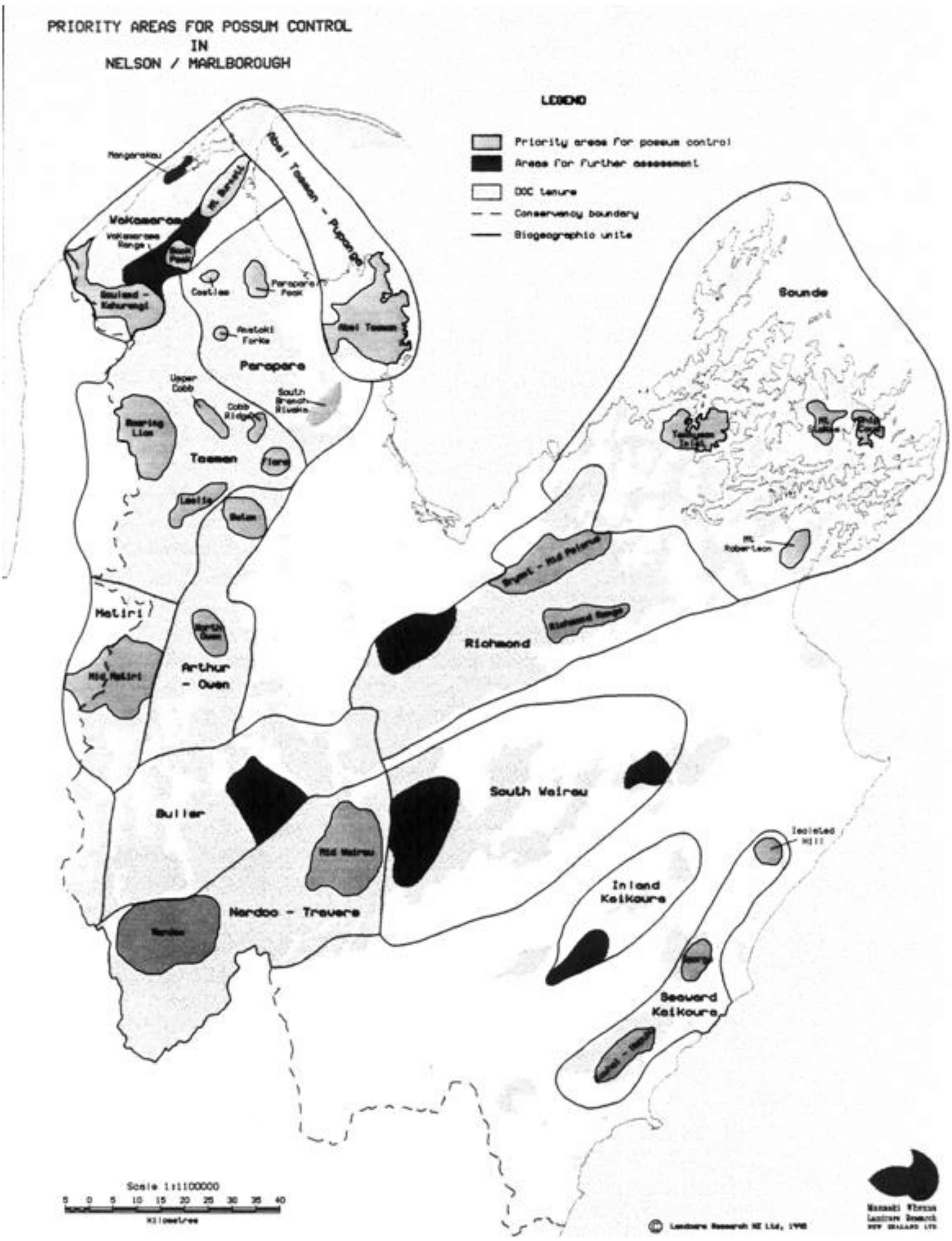

Figure 1. Map units used to aerially assess 265 140 ha of forest for canopy composition and dieback in Nelson/Marlborough. The shaded areas are DOC administered land (approx 1 000 000 ha) (source: Rose, Platt et al. 1995).

- Using copies of the marked 1:50 000 maps to navigate, for each map unit four factors were visually estimated in five classes (< 1%, 1–10%, 11–30%, 31–50%, > 50%):

1. The overall canopy cover of southern and/or northern rātā, or Hall's tōtara in the absence of rātā.
2. The overall cover of seral forest dominated by possum preferred species.
3. The overall proportion of conspicuous canopy dieback of possum-preferred species in the mature forest.
4. The overall amount of beech dieback.

- Two further factors were recorded:
    1. The presence/absence of locally heavier dieback of possum-preferred canopy species in the mature forest.
    2. The presence/absence of conspicuous dieback for seral forest dominated by possum-preferred species such as fuchsia, wineberry, and five-finger.

In all cases, the main species involved were listed. Typical helicopter survey results are summarised in Table 1.

Table 1. Typical aerial survey results for Nelson/Marlborough, summarised for individual map units in two areas (source: Rose, Platt et al. 1995).

Location	Map Unit	Canopy cover (%)			Mature Forest dieback (%)			Species showing dieback				Seral forest dieback	Dieback class
		Rātā	Hall's tōtara	Seral forest	Beech	Possum-preferred species		Rātā	Hall's tōtara	Kāmahi	Tawa		
					Overall	Overall	Localised						
PELORUS													
Rainy R	1	5	+	5	5	5						Y	LIGHT
Fishtail Stm	2	5	+	5	20	5						Y	LIGHT
Echo, Richmond Stm	3	20	+	5	20	5	20	Y				Y	LOCALISED
Pelorus R head	4	5	+	5	5	5							INTACT
Mates Ck	5	5	+	5	20	5						Y	LIGHT
Roebuck, Weka Ck	6	5	+	5	5	5							INTACT
Rocks, Mahanga Ck	7	20	+	5	20	20	20	Y				Y	MODERATE
Captain, Scotts Ck	8	5	+	5	20	5						Y	LIGHT
ROBERTSON													
Pukaka Valley	1	5	+	20	20	20	20	Y		Y	Y	Y	MODERATE
Whites, Robinhood Bay	2	5	+	20	5	5	20	Y	Y	Y		Y	LOCALISED
Stace Ck head	3	5	+	20	20	20	20	Y	Y	Y	Y	Y	MODERATE
Graham R	4	5	+	5	5	5	20	Y	Y	Y		Y	LOCALISED

- Survey results were digitally mapped and summarised as tables. Maps showed average rātā canopy cover and overall dieback (excluding beech dieback) recorded for each map unit. Four dieback classes were mapped, reflecting the low overall amount of dieback in the study area:
  - Intact: < 10% overall mature forest dieback, no localised heavier dieback, and no detectable seral forest dieback.
  - Light: < 10% overall mature forest dieback and no localised dieback, but with conspicuous seral forest dieback.
  - Localised: < 10% overall mature forest dieback but with localised heavier patches and seral forests usually showing conspicuous dieback.
  - Moderate: 11–30% mature forest dieback, usually with localised patches of heavier dieback and seral forest dieback.
- To help clarify the role of possums in dieback, during the aerial survey several close aerial inspections were made of tree crowns with conspicuous dieback, mainly in remote areas. After the aerial survey, brief ground inspections of browsing damage and crown death were conducted at 21 sites showing visually conspicuous dieback. The sites and transects were selected subjectively, as the inspections were designed to help describe dieback areas, not to obtain averages for full map units. At each dieback site, at least 50 trees of possum-preferred species were assessed as they were encountered along 10–20 m wide belt transects. All such trees were assessed, whether or not they showed dieback. For live trees, possum browsing and crown death were visually estimated in five classes (0%, 1–25%, 26–50%, 51–75%, > 75%). Standing dead trees were recorded. For each site, browsing, crown death, and mortality were summarised by species.

Stage 3: Identify priority areas for possum control

- The original 14 management units in the Conservancy were modified and refined into 13 'biogeographic units' with distinct forest composition, climate, geology, and topography. These units formed the basis for developing a strategy to protect a representative range of forest communities.
- For each unit, information on gradients in forest composition, forest susceptibility and the present extent of possum-induced damage, possum vulnerable flora and fauna, possum and ungulate populations, and present and planned possum control operations was summarised.
- Within each unit, priority areas for possum control or further assessment were selected that best represented the range of species, communities, and ecosystems vulnerable to possums. Wherever possible, emphasis was placed on selecting areas containing vulnerable ecosystems (i.e. with a high proportion of co-occurring vulnerable species and forest communities).
- The locations and boundaries of the biogeographic areas and priority areas were digitised and mapped.

Results

Stage 1: Information review

- The most susceptible forest types were in the Seaward Kaikōura, Wakamarama, Marlborough Sounds, and Abel Tasman management areas; 'Special Vulnerable' flora were most susceptible in the Seaward Kaikōura, Wakamarama, and Richmond areas; and the highest priority areas for protecting threatened fauna were Wakamarama and Parapara.

- Most possum populations were post-peak. The only area possibly with colonising populations was in the central Tasman Mountains. The areas with the best geographic barriers to dispersal were islands and peninsulas in Abel Tasman and Marlborough Sounds. Red deer, goats and pigs were widespread and of low priority for evaluating possum control priorities.
- Overall the most susceptible areas were Wakamarama and Seaward Kaikōura, and the least susceptible were Nelson Lakes, South Wairau, and Mātakitaki.

Stage 2: ACS

- Although possum-preferred species were widespread, they were only locally dominant. For example, rātā (mainly southern rātā) was present in 85% of the forests surveyed, but accounted for > 10% canopy cover in only 25% of these forests. Seral forest accounted for 5–10% cover in most survey areas. It was most abundant in Kaikōura (60%) and least in Robertson (15%). Typical species included fuchsia, wineberry, māhoe, five-finger, mountain ribbonwood, tawa, and kāmahi.
- Overall, conspicuous dieback of possum-preferred seral or mature forest species was recorded in 70% of the survey area, with mature forest dieback in 47% of the area and seral forests dieback in 51% of the area (Fig. 3). The least dieback was recorded for Anatoki (100% intact) and the most was for Mt Stokes and Robertson (> 50% localised dieback, > 35% moderate dieback).
- Dieback of possum-preferred species seldom affected more than 10% of the mature forest canopy in any map unit or survey area, reflecting the low overall proportions of these species. Only 4% of the forests surveyed showed moderate dieback and none showed heavier dieback.
- Most dieback of possum-preferred species was localised (42% of the study area), affecting small patches of mature and seral forest in otherwise beech-dominated forests.
- Ground inspections showed that browsing by possums was strongly implicated in aerially observed dieback of palatable species. For all live trees sampled in dieback areas (n = 2331), 60% showed obvious browsing damage and 21% were classed as moderately to severely browsed (i.e. > 25% of the crown browsed). There was widespread browsing on southern rātā and Hall's tōtara (> 40% browsed, > 10% moderately to severely browsed; n = 705 and 207, respectively). Overall, the most heavily affected species were the seral small trees fuchsia and five finger (> 80% of trees browsed, > 33% moderately to severely browsed; n = 143 and 50, respectively).
- In dieback areas, 19% of live trees showed moderate to severe crown death (i.e. > 25% of the crown affected). The most heavily affected species included fuchsia (44%), southern rātā (36%), and Hall's tōtara (28%).

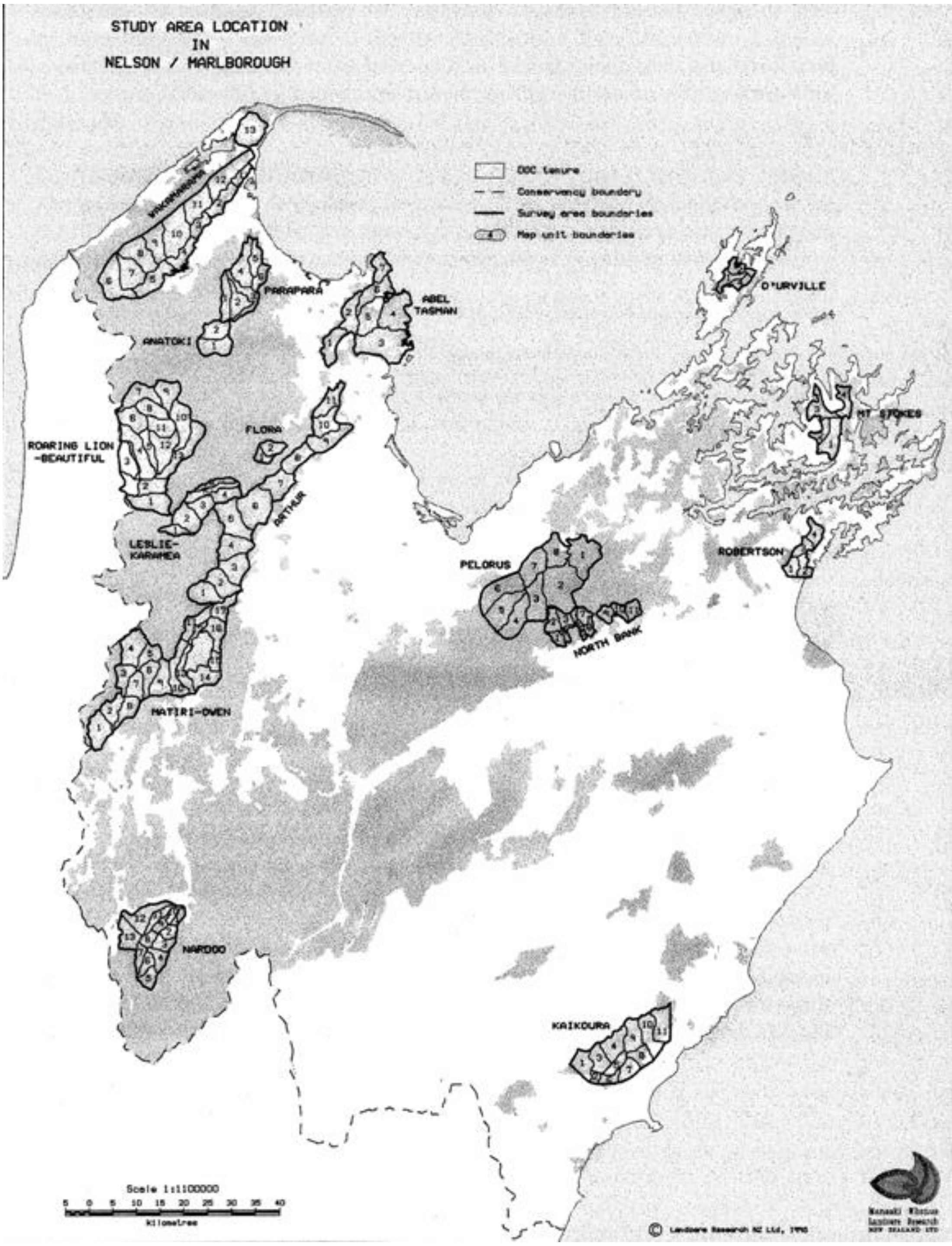

Figure 2. Dieback of possum-preferred species assessed from aerial surveys of 16 areas in Nelson/Marlborough.

Stage 3: Identify priority areas for possum control

- Each biogeographic unit contained 1–6 priority areas for possum control or further assessment of possum impact and conservation values. In total, 34 areas were selected, of which 26 were of high priority for possum control (Fig. 3).
- All 26 areas rated high to very high national priority for possum control using the standard DOC ranking method (Department of Conservation 1994). However, the standard method

emphasised 'distinctive' species and communities, and did not explicitly seek to protect a representative range of common but vulnerable ecosystems. Such ecosystems represent a major proportion of a region's biodiversity.

- Evaluation of control priorities using a combination of biogeographic units and the standard DOC method produced a more comprehensive control strategy than that based on the DOC method alone.

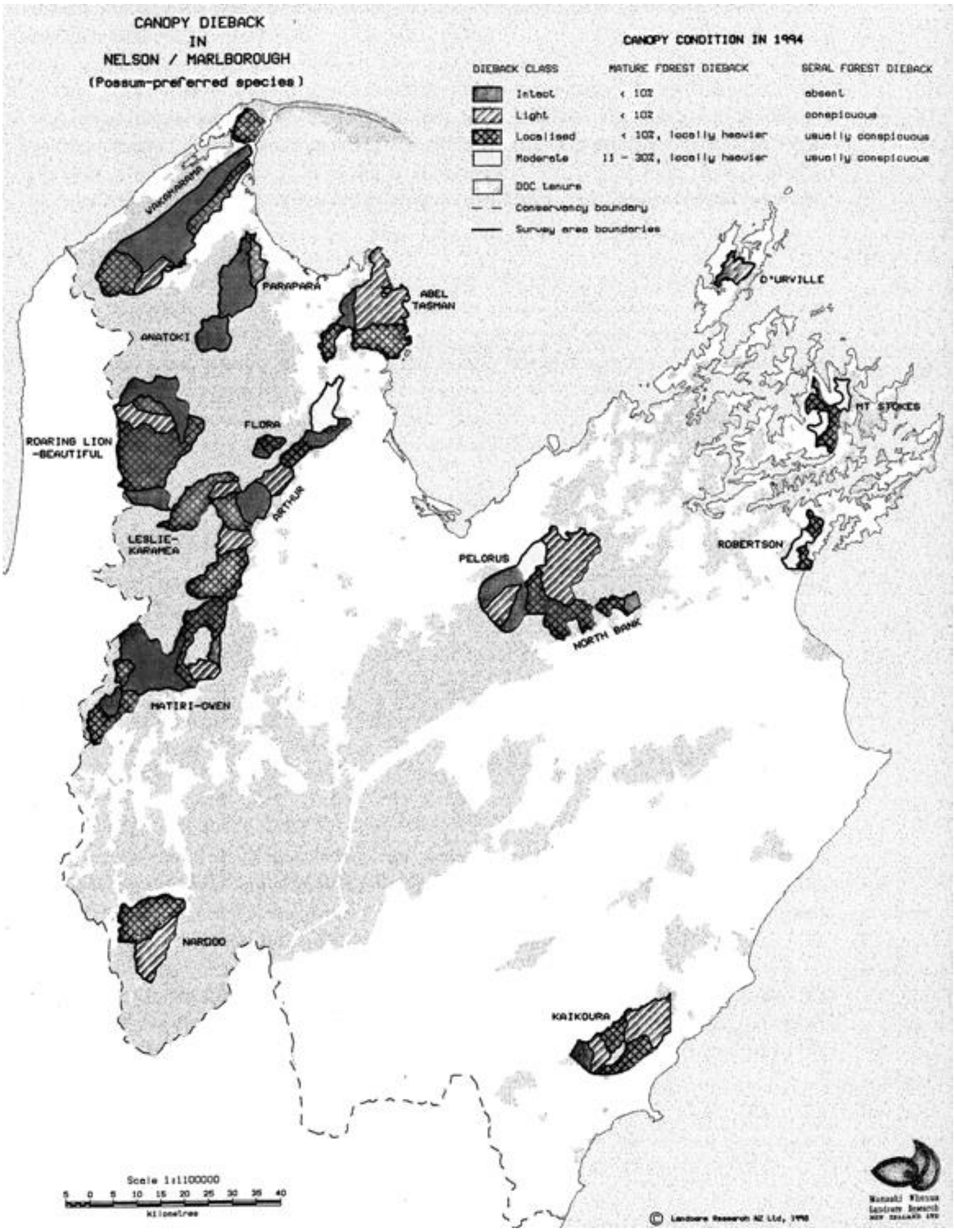

Figure 3. Priority areas for possum control and further assessment in Nelson/Marlborough (source: Rose, Pekelharing et al. 1995).

Limitations and points to consider

- The resources required to conduct a full information review should not be underestimated. The review accounted for about one-third of the total budget, the aerial surveys and ground inspections accounted for about 65%, and only about 2% was used to collate all the information to recommend priority areas. Availability of information to review should also be considered, for instance, the plot data stored in NVS is not comprehensive for all conservancies.
- As all data collected for the review and ACS was digitised in TERRASOFT it could have been overlaid digitally. This would have been a major exercise considering the large number of factors examined and the different scales of investigation and knowledge. Such integration was done manually—integration involves detailed ecological interpretation, not simply digitally overlaying the various layers.
- Depending on resources, ground inspections could be made more intensive, systematic, and statistically robust, e.g. using the foliar browse index method (Payton et al. 1999). Ideally for each dieback area, ground inspections should also sample a similar non-dieback area. This would further clarify the role of possums in contributing to canopy dieback. The assumption in this study was that browsing intensity was lower in non-dieback areas. Resources did not permit fully testing this assumption, but several informal inspections were made of non-dieback areas, which showed a lack of intensive browsing.

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Full details of technique and best practice

Delineating map units

First divide the survey area into map units drawn on NZMS 260 (1:50 000) maps. Map units are also the basic polygons used for entering, storing and analysing most of the digitised data in a Geographical Information System (GIS) and/or spreadsheets. Each map unit should be a single forest block which can be adequately viewed and assessed in one flight pass from a helicopter. Units are typically tracts of forest about 1–2 km^2 in area with readily identified natural boundaries such as creeks, ridges, and bluff systems. Units of this size are a practical recommendation only—for a specific survey they may be made smaller or larger, depending on objectives, resources, and survey complexity. So far, most ACS studies have been in mountainous terrain, where map units are commonly 1–2 km long and extend from valley floor to treeline. Other approaches could be used in gentler terrain or areas with less well-defined topographic boundaries, e.g. by gridding the survey area into contiguous, more-or-less even sized units. For an intensive survey of a relatively small area, map units might be quite small and reflect strata selected for specific objectives, such as elevational bands, distance from the coast, or one dominant forest type. In contrast, for an extensive survey of fairly homogeneous canopies, Rose et al. (1993) used large units marked on 1:250 000 maps to assess beech forest in part of South Westland.

Note that the initial boundary and size of a map unit is not irrevocable, and may be modified to reflect distinct boundaries in canopy cover and/or condition that become apparent as the aerial photograph analysis or helicopter-based survey progresses.

For large surveys, or in very broken terrain, there may be several hundred map units/polygons to be assessed, mapped, analysed, or perhaps to be re-surveyed at a later date. Therefore each map unit must be uniquely numbered (see ‘Minimum attributes’). If digitally mapping the map units/polygons, it is recommended that map units are digitised after the survey, in case the boundaries, number, and names of units change during the course of the survey.

Assessing canopy dieback and composition

Canopy dieback and composition are assessed from a combination of aerial photographs and/or helicopter-based aerial surveys. It is important to note that the aerial photographs and the aerial survey are each only snapshots at a point in time and observers can only score dieback that is currently visible. Canopy dieback is a dynamic process, so that the amount and conspicuousness of dieback change over time. Old dieback events may not be visible to observers as standing dead or defoliated trees because they have collapsed, and areas of light or moderate dieback may have undergone a more severe dieback event in the past (see Rose et al. 1992, table 5). Conifer-broadleaved forest with unusually open upper canopies and abundant regeneration of unpalatable species like pepperwood (*Pseudowintera colorata*) and quintinia (*Quintinia acutifolia*), or herbaceous communities growing in areas where seral forest might be expected, can be indicative of old dieback and should be noted and investigated further (e.g. Rogers & Leathwick 1997). Rose et al. (1992) estimated that although 29% of Westland rātā-kāmahi forest showed light dieback in 1988, over half of this percentage had experienced heavier past dieback.

The methods used to assess dieback and forest composition depend on species composition and structure. Try to estimate canopy composition and dieback for mature and seral forests separately. However, if there has been widespread disturbance resulting in a complex mosaic of mature and seral forest, they may need to be lumped as 'disturbed forest', either for all or some individual map units.

Aerial photograph analysis

Aerial photographs are of most use when the canopy is dominated by possum-preferred species such as rātā, kāmahi, and Hall's tōtara. They will be of limited use when the canopy is dominated by beeches or other relatively unpalatable species. For each map unit, the most recent monochrome or colour aerial photographs are assessed by two or three skilled observers to determine the present amount of conspicuous canopy dieback (defoliation and mortality). While the photographs may be registered in GIS for ease of mapping, assessment is most easily done from hard copies. Low power magnification may be required. Preferably draw in the map units and assess dieback on the original photos. If you do not want to mark the originals, then mark the map units on colour copies, but keep referring to the originals to confirm the dieback score. If there are obvious dieback boundaries within a map unit it can be split appropriately and re-defined. To assess current dieback, preferably aerial photographs should be < 5 years old (certainly < 10 yr) and at scales of 1:25 000 or finer. However, older aerial and historical photographs can still be useful for interpretation, e.g. to elucidate early dieback patterns that may be no longer visible because the trees have collapsed (e.g. Rogers & Leathwick 1997).

Mature forest and 'disturbed' forest

For the mature forest, or for 'disturbed' forest where mature and seral forests are indistinguishable, assign canopy dieback estimates from the aerial photographs to clearly defined quantitative dieback classes that represent the proportion of the map unit affected. Dieback classes must be consistently applied over the study area and recorded so they can be applied in any future measurements or comparisons. The estimates should involve at least two and preferably three experienced observers; if they disagree, the map unit needs to be re-assessed until consensus is reached. In practice it has been found that estimates by experienced observers usually agree well. Representative photographs of each class must be consulted regularly and archived with the data. Use 10% dieback classes, with the addition of a class for < 1% (Table 2). (For reference, the 10% classes can be photocopied from Payton et al. 1997, appendix 5.) Canopies with < 10% dieback have been considered relatively intact in most publications. The scale forces the observers to score as intensely as reasonably possible, but classes are often combined for analysis and mapping as < 10% (light or intact, sometimes with localised heavier dieback), 11–30% (moderate), 31–50% (heavy), and > 50% (severe) (Table 2; see 'Case study A').

Table 2. Classes typically used for scoring and mapping dieback. The same % classes are used for scoring and mapping composition.

Scoring classes (%)	0	< 1	1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80	81–90	> 90
Mapping classes	LIGHT or INTACT (no localised heavier dieback present). LOCALISED (unit contains localised heavier dieback)			MODERATE			HEAVY			SEVERE		

When re-surveying an area, use the same classes as previously used or finer classes that can be lumped into the previous classes for comparison—coarse classes cannot be split retrospectively. Qualitative classes (e.g. light, moderate, heavy) should not be used for scoring as they can be difficult to interpret. However, such terms are useful for expressing clearly defined quantitative classes in reports and publications (Table 2). In developing the method, Rose et al. (1992) used four strictly defined qualitative classes for the aerial photo analysis, but then assessed selected examples of each class from a helicopter to estimate the percentage of canopy affected.

Seral forest

Attempt to estimate seral forest dieback separately from mature forest dieback. If this proves impossible, combine them as 'disturbed forest', as above. Seral forests dominated by short-lived, possum-preferred species like fuchsia, hoheria, māhoe, or patē are key indicators of possum impact and frequently collapse in the early stages of invasion. Unfortunately, they can also be difficult to detect on aerial photographs because they are restricted to small, disturbed sites such as gullies or slips, or obscured by the surrounding forest canopy. Attempt quantitative estimates of both the proportion of seral forest and the proportion of seral forest dieback per map unit, using the same scale as for mature forest (Table 2). Quantitative estimates may be too difficult and best left for the helicopter-based survey. However, at a minimum record the presence/absence of seral forest and presence/absence of seral forest dieback for all map units. Seral forest dominated by unpalatable species, like mānuka, can also be assessed, but is not particularly relevant to assessing possum impacts.

Helicopter-based aerial survey

After analysing the aerial photographs, a rapid helicopter-based survey is made of all or selected map units/polygons to help verify and interpret the patterns identified on the photographs (Rose et al. 1992). The aerial survey will be the prime method for mapping and scoring dieback if there are no recent aerial photographs available, or for forest types with low proportions of possum-preferred canopy species, such as beech-broadleaved hardwood forest (Rose 1994; Rose, Platt et al. 1995).

In virtually all circumstances a fixed-wing aircraft will be inadequate as it is not sufficiently manoeuvrable or capable of hovering for close inspections of individual trees.

Survey as many units as resources permit. It may be necessary to inspect all map units, especially if aerial photographs are not available. Record the flight path into a GPS unit.

If selecting a sub-sample of map units, they should cover:

- As many map units as possible
- The range of dieback classes scored on the aerial photos
- The range of forest composition in the study area, with emphasis on canopies highly-preferred by possums
- As many map units as possible containing possum-preferred seral forest
- The range in history of occupation by possums, if known
- Gradients in any other factors known (or considered likely) to affect the amount of dieback, e.g. parent material, distance from the coast

The aerial survey involves scoring several canopy composition and dieback variables for each map unit/polygon (see 'Minimum attributes'). Unless otherwise stated, for all variables use the same scale as for the aerial photograph analysis, i.e. 10% classes, with the addition of a < 1% class (Table 2). The 10% classes are illustrated in Payton et al. 1997 (appendix 5). Canopies with < 10% dieback have been considered relatively unmodified by possums in most publications. The scale forces the observers to score as intensely as reasonably possible, but classes are often combined for analysis and mapping (Table 2; see 'Case study A').

The aerial survey requires intense and prolonged concentration for about 2–6 hours per day, often under difficult conditions. Normally the helicopter doors will be on as they do not impair scoring—note there is also a higher risk of losing data with the doors off. To ensure optimum quality, flying should be terminated if observers begin to lose concentration or feel unwell. Each observer records their own data.

For most surveys it is best to have three observers. Two of these concentrate on scoring alone. In steep country, they should be seated on the side of the helicopter nearest the hill side. Binoculars are not usually necessary, but may come in handy for closer inspections. It is best to have a third observer seated next to the pilot who holds the map and is primarily responsible for navigation and communication with the pilot and other observers. Pilots familiar with this type of work are advantageous because good communication between the pilot and observers is essential. The proposed flight path and polygons may be supplied to the pilot in advance. The navigator ensures the pilot maintains the optimum altitude, distance and speed for scoring, indicates to the main observers which map unit is being assessed, when it starts and stops, and generally sees that things are going smoothly. The navigator also attempts to score all map units, depending on the conditions and the complexity of the survey, and should at least note map units containing mature- or seral-forest dieback. If a main observer has difficulty scoring a map unit, it may be necessary to descend to canopy level, use binoculars and/or re-fly the unit. To reduce bias, the navigator should be the only observer with access to any pre-prepared dieback maps from the aerial photo analysis.

Two experienced observers capable of scoring and navigating are sufficient for fairly straight-forward surveys (e.g. dominantly beech forest). They should both be in the front of the helicopter and not have access to any pre-prepared dieback maps from the aerial photograph analysis.

The map unit is the primary unit of assessment, and hence should be as small as feasible given the wide scale of the survey (tens to hundreds of thousands of hectares). The aim is to traverse each map unit smoothly in one representative sweep and estimate overall values for each canopy composition and dieback parameter being assessed. Depending on objectives, there will usually be several factors to assess, such as the proportion of rātā in the canopy, the amount of mature forest dieback and the main species involved, the presence of localised heavy dieback and the main species involved, the proportion of seral forest and seral forest dieback and the main species involved. Estimating all these factors at perhaps 80–100 km/hr for 100 map units is mentally challenging! Therefore it is not usually feasible to provide exact, detailed data on location, composition and dieback within all map units. A GPS unit is invaluable if the objectives dictate that particular sites need to be exactly located (e.g. potential permanent plot sites). However, this should not detract from the primary aim of providing an overview for each map unit.

Total helicopter flying times depend largely on forest complexity (the speed of assessment) and the remoteness of the study area (positioning time). As a guide, it took about 10 hours of flying to assess 165 000 ha of mixed beech-broadleaved forest in South Westland and about twice that time to assess 265 000 ha of similar forest in Nelson/Marlborough.

Determining the optimum height, distance, and speed for scoring map units requires trial and error and there are no hard and fast rules. The helicopter should be positioned high enough to allow a good overview of the forest canopy that is being assessed but close enough to the canopy for observers to see the early stages of dieback. Additionally, high-priority palatable species may be restricted to particular elevational bands or landforms. For example, the most susceptible Westland rātā-kāmahi forests were between 500 and 900 m elevation and these were surveyed from about 1000 m altitude and 500 m from the hillside (Rose et al. 1992). As well as obtaining an overview, for near-pure beech forest it may be appropriate to spend extra effort on relatively uncommon communities and species that are highly susceptible, such as sporadic mid-slope Hall's tōtara, clumps of southern rātā on bluffs and spurs, and thin strips of seral fuchsia, hoheria, and wineberry lining gullies (Rose et al. 1993; Rose, Platt et al. 1995). Ideally the presence and general locations of these species, communities and sites should be known before the survey, by reviewing relevant information. Much of this will not be apparent on aerial photographs (unless they are fine scale and in colour).

Because the assessment is subjective, observers' scores will not always be identical. However, it is important that a reasonable consensus is achieved for all map units. Before the survey, the observers need to be calibrated and become familiar with the scoring system by discussing their impressions while flying several map units. During the survey, observers record their individual scores for each map unit, but they also need to communicate well with each other and if they are having difficulty perhaps re-assess a map unit (this is better than having to pay for another flight). A de-briefing session should be held immediately after a maximum of about 2 hours of flying—often a break will be required or it may coincide with a convenient re-fuelling. At the de-briefing, all observers should discuss and compare their recording sheets and decide whether any map units need to be re-assessed. Particular emphasis needs to be placed on positively identifying forests that are relatively intact (< 10% dieback).

For each map unit/polygon, several composition and dieback variables are scored by each observer using the same scale as outlined in Table 2. The variables include (see 'Minimum attributes' for more details):

- Mature or 'disturbed' forest canopy composition—possum-preferred species: Estimate the proportions of the main possum-preferred species in the mature-forest canopy (e.g. southern rātā, northern rātā, Hall's tōtara). When seral forests cannot be separated from mature forests they are assessed together as 'disturbed' forest. For each of the main palatable species, estimate canopy cover in the same classes used for the aerial photograph analysis (Table 2).
- Mature or 'disturbed' forest dieback—possum-preferred species: For possum-preferred species, estimate the proportions of dead and conspicuously defoliated canopy trees in the mature or disturbed forest. Use the same scale as for canopy composition (Table 2) and note the main species showing damage.
- Mature or 'disturbed' forest dieback—non-preferred species, e.g. beech forest: When map units are dominated by beech, or other non-preferred species, estimate the overall proportion of the mature forest canopy affected by dieback of such species (Table 2). This provides an indication of the extent to which factors other than possum-browsing (e.g. storm damage, pathogens) may be contributing to dieback of the relatively uncommon possum-preferred species.
- Localised mature or 'disturbed' forest dieback: For all map units assessed as having < 10% overall mature- or disturbed-forest dieback, record the presence/absence of localised heavier dieback of possum-preferred species and assign a local percentage of dieback score for the site(s) affected (same scale as above). It is important to record both presence/absence and percentage of dieback, (Table 2) as quantitative estimates may be difficult. Localised dieback is particularly useful for forests with naturally low proportions of palatable species (e.g. beech-broadleaved hardwood forest), or in the early stages of possum invasion.
- Seral forest composition: When seral forest can be separated from mature forest, record the proportion of the map unit occupied by seral forest dominated by possum-preferred species such as fuchsia (Table 2). Also record the main species in the canopy. If seral forests cannot be separated from mature forests, then incorporate them under disturbed forests, as above.
- Seral forest dieback: For seral forests dominated by possum-preferred species, record the presence/absence of conspicuous dieback and an estimate of the amount of conspicuous dieback (Table 2). It is important to record both presence/absence and percentage of dieback, as quantitative estimates may be difficult to apply consistently. Record the main species showing damage. If seral forests cannot be separated from mature forests, then incorporate them under disturbed forests, as above. Seral dieback is again a key indicator of impact for beech forests or in the early stages of invasion. Seral forest dominated by unpalatable species, like mānuka, can also be assessed, but this is not particularly relevant to assessing possum impacts.

Rapid ground and aerial inspections

During or after the helicopter-based survey, rapid aerial inspections and/or ground inspections of key possum-preferred species are made at selected sites showing dieback. The main aim is to briefly assess the current severity of possum browsing and whether this could be a primary factor involved in dieback (Rose, Platt et al. 1995). Aerial inspections usually will be made in the more remote parts of a survey area, or will result from the need to clarify the situation immediately for the observers during the helicopter-based survey. For example, during a helicopter-based survey in Nelson/Marlborough, thin-crowned southern rātā, tawa, and tree fuchsia were confirmed as having intense possum browse by hovering within a few metres of the trees (Rose, Platt et al. 1995), as for aerial FBI. Ground inspections are generally made after an area has been scored from a helicopter.

Usually, rapid ground and aerial inspections will not be appropriate for statistical analysis or representative of the whole map unit or survey area because the sites are subjectively chosen to represent areas of observed dieback. The number of sites visited will be restricted by access, personnel costs and flying time. Typically sites will be chosen to clarify specific issues that have arisen from the helicopter-based survey, such as whether Hall's tōtara and southern rātā with light dieback are drought-stressed and/or being defoliated by possums, or whether coastal dieback reflects browsing and/or the effects of salt spray. Ground inspections will generally be planned after the helicopter work, but aerial inspections often will be opportunistic and concurrent with the main survey. The locations of all areas visited must be entered into a GPS unit.

Ground inspections are made by two or three observers at selected sites after the aerial survey (Rose, Platt et al. 1995). The aim is to assess as many trees as possible, but spend only about a day at each site. For each site, a total of at least 50 trees of possum-preferred species are assessed as they are encountered along 10–20 m wide belt transects of fixed bearing and variable length. For each species, record the number of dead standing trees (excluding old spars without intact bark), and dieback and possum browse for live trees. Score dieback and browse using the modified Braun-Blanquet scale, as in the foliar browse index method (< 5%, 5–25%, 26–50%, 51–75%, > 75%; Payton et al. 1999).

If more formal/detailed ground-based assessments are to be conducted, they should include paired dieback and non-dieback areas with similar forest composition and site factors. This depends heavily on resources and objectives. Appropriate methods for such assessments include ground and aerial FBI for assessing possum browse, dieback and canopy condition, and RECCE and 20 × 20 m permanent forest plots for assessing forest composition and structure.

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Appendix A

The following Department of Conservation documents are referred to in this method:

docdm-146272	Standard inventory and monitoring project plan